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Optimal Level of Expenditure to Control the Southern Pine Beetle

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Contents

Page
Study Overview ,
Procedures
Economic Model
Days of Infestation Growth, . 6
Simulation of Volume Loss 7
Results12
Conclusion and Discussion
Appendix: Tables by Region and State for Optimal Level of SPB
Control19

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ABSTRACT

The optimal level of expenditure to control damage to commercial timber stands by the southern pine beetle (SPB) was determined by models that **Simu-**lated and analyzed SPB attacks during a typical season for **11** Southern States. The optimal level was defined as that which maximized the dollar value of timber saved minus the cost of control (i.e., maximized net benefits). Real discount rates of 4 and 10 percent were used. At 4 percent, maximized net benefits for the entire Southern region are estimated at about \$50 million, or a benefit/cost ratio of 6.22; at 10 **per-**cent, more than \$30 million, or a benefit/cost ratio

of 5.93. Alabama, North Carolina, and Texas warrant the largest control programs; Georgia, Louisiana, South Carolina, and Mississippi, moderate programs. Virginia, Tennessee, Arkansas, and Oklahoma justify small control programs. Methods and costs for detection, evaluation, and suppression of SPB infestations are discussed.

Keywords: <u>Dendroctonus frontalis</u>, <u>CLEMBEETLE</u>, OVERFLIGHT, <u>BEAM</u>, <u>cut and leave</u>, <u>cut and salvage</u>, presuppression flights.

Study Overview

This study was conducted to assist State & Private Forestry and various State forestry agencies in the planning and implementation of more efficient southern pine beetle (SPB) control activities. The purpose was to determine the most economically efficient (optimum) level of expenditure to control SPB damage to commercial timber stands in Al abama, Arkansas, Georgi a, Loui si ana, North Carolina. Mississippi, Oklahoma. South Carolina, Tennessee, Texas, The basic geographic units of analysis were 16,141 Forest Inventory and Analysis (FIA) survey plots located within the study area. Each plot represented about 4,500 acres of a particular forest stand/site condition. These survey data were obtained from both the Southeastern and the Southern Forest Experiment Stations. The final results of the economic analysis were summarized and reported by State and by the following land ownership classes: Federal, State, forest industry, and noni ndustri al pri vate (NI PF).

The three major components of the analytical system used were the CLEMBEETLE stochastic simulation model, the Beetle Economic Analysis Model (BEAM), and the OVERFLIGHT simulation model. CLEMBEETLE is written in IBM-FORTRAN 77 and was developed by Roy Hedden. BEAM is programmed within the Statistical Analysis System (SAS) to run on an IBM computer; OVERFLIGHT is written in BASIC to run on an Apple IIe microcomputer. The latter two programs were developed by J.E. de Steiguer.

Using FIA survey plot data, CLEMBEETLE simulated SPB infestations

and the volume of timber lost to SPB for a single day of infestation growth. The OVERFLIGHT model calculated the total number of days that SPB infestations would grow during the course of a single SPB season if (1) no detection takes place (i.e., without control) and (2) various levels of detection are undertaken (i.e., with control). Within BEAM, the simulations generated by CLEMBEETLE and OVERFLIGHT were combined with data from the State forestry pest control officers and other sources concerning control practices and costs, salvage rates, and stumpage prices to obtain estimates of the benefits and costs at the various levels of control. BEAM selected the optimum level of control for each survey plot, and these optima were summed and classified according to State and ownership class. The optimum level of control was defined as that which maximized the value of timber saved less the cost of saving the timber.

Procedures

Economic Model

The optimal level of SPB control was defined as that which maximized net benefits. Net benefits were defined as the present value of timber losses averted due to control minus the cost of control. The analysis simulated SPB damage that could be expected with and without control during a single year, given a typical level of SPB population. This typical level of SPB population was based on average beetle populations over the past 10 years.

The basic geographic units of analysis were 16,141 FIA survey plots, each of which represented about 4,500 acres of a particular forest stand/site condition. Each plot was treated as an independent forest management unit. Plots could be aggregated to multicounty areas called Survey Units, and Survey Units could be aggregated to State l evel s. The forest owners were assumed to be profit-maximizing producers of pul pwood and sawtimber who did not consider the amenity values of the forest when making pest management decisions. Atomistic competition was assumed so that the actions of any single producer would not influence market output or prices. Also, forest managers were assumed to have perfect knowledge regarding future timber markets, prices, and the consequences of their pest management strategies.

Timber losses due to SPB were treated as small, isolated openings in the existing forest stand which had no effect on future stand rotation schedule or on annual management costs associated with the current stand. Furthermore, timber losses were not compensated by increased growth in the residual stand. All pest management costs were treated as variable.

With these qualifications and assumptions, it is now possible to derive a general solution for the optimal level of SPB control expenditure. The general solution will then serve as a basis for presenting the BEAM model. First, consider a forest stand (FIA survey plot) which is currently "n" years of age and is attacked by SPB. If no action is taken to control damage, the owner expects to lose a volume of timber equal to Q_{\bullet} This volume (Q,) represents the total amount of timber which will be lost to SPB, and consists of the currently standing volume plus the growth that would have been added by the anticipated year of harvest (T). The present value of losses without control (L,) is:

$$L_o = Q_o P/(1+i)^{T-n}$$
 (1)

where:

P = **stumpage** price at harvest i = discount rate

If, instead, some type of SPR control is elected, the owner will lose some lesser volume of wood (Q,), but will also incur a control cost (C). The value of losses with control (L,) may he written as follows:

$$L_w = Q_w P/(1+i)^{T-n} + C$$
 (2)

The net benefits (NR) of control are found by deducting equation (2) from equation (1) with the following result:

$$NB = (Q_o - Q_w) P/(1+i)^{T-n} - C$$
 (3)

The forest owner will undertake SPB control as long as the net benefits of control are positive. In other words, control is desirable if the present value of timber losses averted (benefits) exceed the cost of control. However, the problem facing the landowner may be more complex than simply deciding between the options of control vs. no control. Instead, the owner may have to choose the most appropriate level of If we assume that by expending more control dollars more timber can be saved, and that $C = f(Q_w)$, then it is possible to derive a theoretical solution for the optimal level of SPB control. If equation (3) is continuous and differentiable, and its shape is concave, first increasing with output and then decreasing, the maximum (optimal) level of net benefits is found where the first derivative of NB with respect to $\mathbf{0}_{\mathbf{W}}$ is equal to zero. Thus, from equation (3) the optimal solution

$$\frac{dNB}{dQ_{w}} = P/(1+i)^{T-n} - f'(Q_{w}) = 0$$
 (4)

Equation (4) can be rearranged to demonstrate that at optimum, marginal benefits will equal marginal costs:

$$P/(1+i)^{T-n} = f'(0_w)$$
 (5)

The foregoing general solution to the problem of optimal SPB control

served as the basis for the BEAM model. However, for BEAM, the basic model was substantially expanded to include factors such as salvage values and the various components of control cost. Also, the optimal solutions were derived through iterative simulations because the damage and control production functions could not be expessed in continuous form.

To understand BEAM, it is necessary to understand the steps involved in the control of SPB outbreaks. SPB control consists of three steps: (1) detection, (2) evaluation, and (3) suppression. Detection is typically conducted from ai rcraft. In the jargon of SPB control, such detection activities are referred to as "presuppression flights." Once infestations have been detected they must then be evaluated. Evaluation is the on-the-ground inspection of each infestation to determine its extent and Evaluation may be followed condition. by suppression, which is the step where action is taken to halt the spread of the infestation. The most common current methods of suppression, according to State forest pest control officers, are cut and salvage, and cut and leave. Both techniques involve cutting a buffer strip around the advancing head of the infestation. With the former method, the cut timber is salvage for sale, whereas with the latter, the timber is simply left on the Detection and evaluation require cash outlays, hence are referred to as direct costs in this study. Suppression involves both direct and in-Direct costs are those direct costs. for tree felling in the case of the cutand-leave method. Indirect costs result from harvesting the financially immature timber that occupies the buffer strip.

The intensity of control was determined by the frequency of presuppression flights. With increasing numbers of detection flights, timber losses were reduced because infestations had fewer days to spread before evaluation and suppression took place. This concept will be discussed later in greater detail. Here, however, it is important

to realize that the intensity of control or the lack of control was reflected in the number of days an infestation was allowed to spread. In BEAM, it was assumed that all infestations, once detected, were evaluated and suppressed, and that all suppression activities were competely effective in stopping the spread of infestations.

From CLEMBEETLE, REAM obtained simulated estimates of the volume of timber that would be lost to SPB per day of infestation growth, per acre of forest type. These CLEMREETLE estimates may be expressed as V+G, where V is the volume of currently standing timber lost and G is the growth that would have occurred had the stand reached some assumed rotation age. For the without-control situation (L,), the present value of timber lost, less salvage value, was calculated as follows:

$$L_{O} = [D_{O}(V+G) P[(1+r)/(1+i)]^{T-n}$$

$$(D_{O}V)aPb] AW$$
(6)

where:

D_o = days of infestation growth without control

P = current timber stumpage prices

r = annual real rate of stumpage
 price increase

1 = real discount rate

T = assumed rotation age

n = current stand age

a = fraction of dead timber salvaged

b = dead timber price as a fraction of green timber price

A = total acres of forest type

w = fraction of Survey Unit in SPB outbreak condition

For the with-control situations (L,), the present value of timber lost, less salvage value plus control costs, was calculated as follows:

$$L_{w} = \left\{ \left[D_{w}(V+G) P[(1+r)/(1+i)]^{T-n} - (D_{w}V)aPb \right] AW \right\}$$

$$+ F + E + SD + SI$$
(7)

where:

 $D_{\mathbf{w}}$ = days of infestation growth with various levels of control

F = direct cost of presuppression flights

E = direct cost of evaluation

SD = direct cost of suppression

SI = i n di rect cost of suppression

The values of the various control cost elements were calculated as follows:

$$F$$
 = number of flights
 x cost per acre of flying
 x total (8)

E = number of infestations
 x fraction of infestations
 controlled
 x cost of visiting an
 infestation (9)

SD = buffer strip size (acres)
 x fraction of acres subject
 to cut-and-leave tree
 felling
 x cost per acre of tree
 felling (10)

SI = buffer strip size (acres)
 x present value/acre of buffer
 strip timber
 current salvage value of
 buffer strip timber (11)

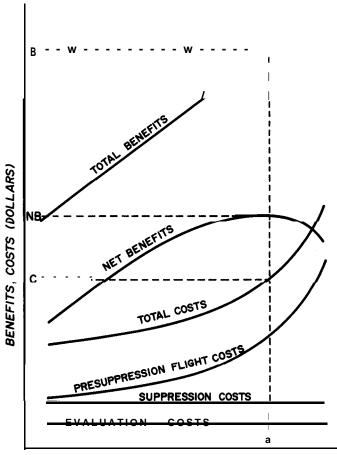
The net benefits (NB) of control were calculated by subtracting equation (7) from equation (6). The result, which represents the present value of losses averted minus the change in salvage value minus the cost of control, is:

$$NB = \{ [(D_o - D_w)(V+G) P[(1+i)/(1+r)]^{T-n} - (D_o - D_w)VaPb] AW$$

$$- F - E - S D - S 1$$
 (12)

In the analysis, eight presuppression flights were simulated for each FIA survey plot. This, in turn, generated eight values for the variable $D_{\mathbf{w}}$. The value of equation (12) was calculated eight separate times, once for each value of $D_{\mathbf{w}}$. From these eight

optional levels of control, the one that yielded the maximum net benefits was selected as the optimum, provided that this maximum value was positive. Figure 1 illustrates the benefits and costs for a typical FIA survey plot. The optimal solutions for the individual plots were summed for the States by forest ownership classes.



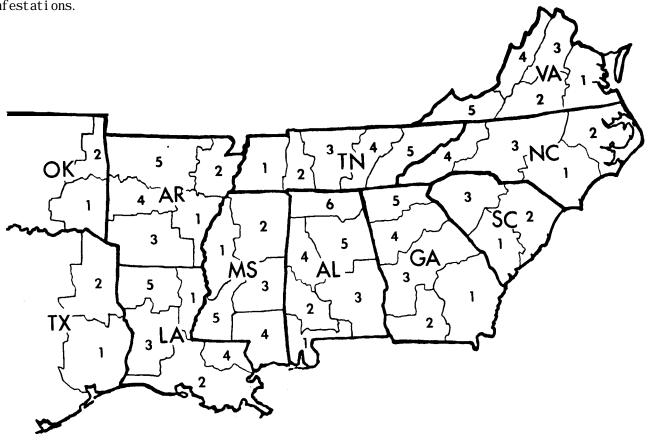
VOLUME OF TIMBER LOSSES AVERTED

Figure 1.--Benefits and costs of SPB control. Optimal volume of timber saved from the beetle (Q) is found where net benefits are maximized (NB). This is the point of greatest distance between total benefits (B) and total costs (C).

Following is a description of the data used in the study. Real discount rates of 4 and 10 percent were used to provide a sensitivity analysis. The real annual rates of stumpage price increase for pulpwood and sawtimber were, respectively, 1 and 2.5 percent. The costs per acre of detection flights

and cut-and-leave land clearing were, respectively, 2 cents and \$500, provided by State & Private Forestry (S&PF) per-The stand rotation ages, obtained from State forestry pest control officers, were 60 years for Federal forest lands, 45 for State-owned lands, 35 for forest industry lands, and 45 for NIPF lands. The current stand ages and the total acres of forest type were obtained from FIA data. The fraction of the Survey Units in an SPB outbreak condition (fig. 2) represents the portion of the area, based on data for the past 10 years, which has had SPB infestations.

The remaining data used in the study are shown in table 1. These include stumpage prices, salvage rates, dead timber price fractions, fraction of buffer strip to which cut and leave was applied, and the cost of evaluating infestations. Stumpage prices were obtained from Timber Mart--South, Inc., and represented average prices for the past 10 years stated in constant 1984 Salvage rates were assumed to dollars. be 50 percent for the without-control situation based on the advice of S&PF personnel.



Survey Unit	AL	AR	GA	LA	MS	NC	OK	SC	TN	TX 	VA
1 2 3 4 5	.22 .53 .40 .50 .46	.37 .03 .00	.04 .41 .73	.03 .53	.71 .08 .60	.30 .50	. 0 (.06 .13 .46			.15 .35 .20 .06

Figure 2.--Map of Survey Units in the States surveyed, and the fractions of these Survey Units in outbreak condition during the last 10 years.

Table 1.--Stumpage prices, timber salvage rates, and control costs, by State

_____T - -

State	Sawtimber prices per fbm, 1984	Pul pwood pri ces per cord, 1984	dead timber	Fraction of green price for dead timber		Fraction of infes- tation cut & left	cost of evaluating infes- tations
	• <u>Dol</u>]	lars_		Perc	ent		\$/spot
AL AR	181.96 175.82	18. 84 13.16	75 50	10/50	99 85	1:	5 5 2 2
GA	196.980	23. 43	66	50	93	7	30 25
MS	178. 64	13.49	50	45	99	1	50
NC	157. 65	9. 92	65	75	99	1	25 25
9K	107. 02	18. ØØ	66	36	89	15	25
TX	17982 52 0	1 37006	60	36	69	40	15 35
VA	103. 14	10. 33	50	50	95	5	25

Table 2.-- New SPB infestation occurrence as a percentage of total annual new infestations, by month and region

Month		Gulf ^a	Pi edmont & Mountain ^b
			Percent
January		0	0
February		2	0
March		3	1
Apri l		13	1
May		14	10
June		17	17
July		25	20
August		13	25
September		7	17
0ctober		3	6
November		3	3
December		0	0
Annual	total	100	100 .

^aAlabama, Arkansas, Louisiana, Mississippi, Oklahoma, Texas.

Days of Infestation Growth

Within the BEAM model, the intensity of SPB control or lack of control was determined by the frequency of presuppression flights, which were simulated during the SPB season. The total number of days that an infestation was allowed to grow, and thus the volume of timber lost, decreased as the number of detection flights increased. The number of days of infestation growth was calculated by the OVERFLIGHT model.

The OVERFLIGHT model used data obtained from State forestry pest control personnel concerning the relative frequency of new infestation occurrence, by region and month, during a typical SPB season (table 2). The average number of days of infestation growth for the without-control situation was calculated by multiplying the monthly relative frequency of new infestation occurrence by the number of days remaining in the SPB season. These products were summed to obtain the weighted average number of days of growth for an infestation. For each of the eight levels of presuppression flights, the

^bGeorgia, North Carolina, South Carolina, Tennessee, Virginia.

flights were placed within the season to minimize the number of days of infestation growth. The monthly relative frequencies were multiplied by the number of days before the next presuppression flight would occur, and summed for the season. Also, an additional 30 days was allowed in the calculations to account for a lag between detection and suppression. The resulting average number of days of infestation growth for the without-control and the eight with-control situations are presented, by region, in table 3.

Table 3.--Average days of growth for SPB infestations assuming various numbers of presuppression flights per season and allowing 30 days between detection and suppression implementation, by region

No. of flights	Gul f" 	Piedmont & Mountain ^b
None	166	136
1	100	91
2	81	74
2 3	73	68
4	67	63
5	62	59
6	60	58
7	59	58
8	59	58

^aAlabama, Arkansas, Louisiana, Mississippi, Oklahoma, Texas.

Simulation_of_ Volume Loss

Volume loss due to SPB attack was generated by using a modification of the CLEMBEETLE program. 1,2 Volume loss consisted of trees actually killed by SPB as well as growth loss due to premature death of the tree. Based on average beetle populations from 1971 to 1980, losses were generated for three population levels by the number of spots per 1,000 acres of pine and pine-hardwood:

low--0.5 spots, moderate--2.0 spots, high--5.0 spots. For each population level, the simulation of loss consisted of the following steps:

- 1. Calculate the probability of an infestation occurring per acre (PROB).
- 7. Generate the number of active trees (AT).
- 3. Calculate the probability of a spot being inactive at detection (PROBI).
- 4. Test to see if the spot is inactive.
- 5. If the spot is inactive at ground check, calculate the number of dead trees (DEADI).
- 6. If the spot is active, calculate the number of trees killed per day (TKD).
- 7. Calculate the number of trees killed in an active spot:

$$DEADA = (TKD \times DAYS) + AT.$$

- 8. Calculate the expected number of trees killed (ELOSS):
 - a. Inactive spots: $ELOSS = PROB \times DEADI$, and
 - b. Active spots: $ELOSS = PROB \times DEADA$.

These steps were repeated 150 times for each FIA survey plot that contained forest types susceptible to SPB attack. The sum of the ELOSS's was divided by 150 to obtain the average expected number of trees killed.

^b**Georgia,** North Carolina, South Carolina, Tennessee, Virginia.

^{&#}x27;Hedden, R.L. Impact sub-models for a southern pine beetle pest management program--Phase I. Unpublished progress report to the USDA Forest Service, IPM Program for Bark Beetles of Southern Pines, New Orleans, LA. 1982. 40 pp.

 $^{^2\}text{Hedden, R.L.}$ Impact sub-models for a southern pine beetle pest management program--Phase I. Unpublished final report to the USDA Forest Service, 1PM Program for Bark Beetles of Southern Pines, New Orleans, LA. $1983.\ 31\ \text{pp.}$

Separate models for probability of infestation were used for the Mountain, Piedmont, and Coastal Plain regions.

Models compatible with FIA survey data were developed for each region from site and stand data collected during the expanded Southern Pine Research and Applications Program. In each region the probability of infestation varies by forest type and the SPB population level. Other variables used were:

	<u>Mountain</u>	Pi e	edmont	Coa	astal Plain
1)	Proportion of pine	1)	Sl ope	1)	Land form (slope)
		2)	Site index	2)	Basal area per acre
		3)	Stand ori gi n	3)	Proportion of pine
				4)	Age

The number of active trees was a function of the number of trees per acre (TPA), with dense stands having a greater number of active trees than did less dense stands. Active trees were generated from an exponential distribution with an expected value of 0.15 x In addition, not all spots will be active (contain attacking adult beetles or developing broods) at the time of In these spots, the average number of dead trees was generated from an exponential distribution with an expected value of 1 tree. In active spots, the number of trees killed was a function of the number of active trees, SPB population level, total basal area per acre, mean stand diameter, and number of days a spot remains active. The expected number of trees killed per acre was the product of the probability of infestation and the number of dead trees.

The expected volume per acre killed by SPB is obtained by multiplying ELOSS

by the average pine volume per tree for each survey plot. The average pine volume per tree is derived from the total pine volume per plot and the number of pine growing-stock trees per For the area covered by the Southeastern Forest Experiment Station, the number of growing-stock trees per acre was derived from the total number of live stems per acre, age, and basal area per acre. Survey data for the Southern Forest Experiment Station did Survey data for the not include the number of live stems per acre; therefore, trees per acre were estimated by forest type, age, and observed basal area per acre.

To determine the reliability of the results of the simulation procedure, actual published data on the volume killed by SPB⁴ were compared for the Southern region. Data for the decade 1971 to 1980 were used in the analysis. For each Survey Unit, predicted losses for the moderate SPB population level (2.0 spots per 1,000 acres) were multiplied by the proportion of the unit area in an outbreak condition in each These adjusted loss estimates were summed to obtain total decade losses by Survey Unit. The unitwide losses were then aggregated to obtain State and region totals.

In order to obtain the loss projections, an estimate of the average number of days a spot is allowed to grow is needed. During outbreak periods, most States make three to four detection flights per year. Assuming the flights were optimally timed and that the spots were either controlled or inactive within 30 days of detection, the average interval of spot growth is:

Number of	<u>Days</u> of	spot growth
flights	<u> Piedmont</u>	Coastal Plain
3 4	68 63	73 67

Price, Tis.; Doggett. C. A history of southern pine
beetle outbreaks in the southeastern United States.
Macon, GA: Georgia Forestry Commission. 1982. 32 pp.

³Coster, J.E.; Searcy, J.L.. eds. Site, stand and host characteristics of southern pine beetle infestation. Tech. Dull. 1612. New Orleans, LA: USDA Combined Forest Pest and Development Program; 1981. 115 pp.

Table 4.--Predicted average annual cubic-foot volume of timber killed by SPB in **10** Southern States

Days of spot growth	Predicted volume killed ^a (ft ³ x 10 ⁶)	Difference between predicted and observed ^b	Percent error ^c
65	131. 235	3. 359	2. 56
70	137.619	9.743	7. 08
71	138.895	11.019	7.93
76	145.279	17.403	11.98

Data for Oklahoma not included because of negligible SPB activity.

When these periods of spot growth were used to generate expected losses, the results in table 4 were obtained.

The results indicate a positive bias in the predictions. An average period of 65 days between spot occurrence and control is probably opti-Reported periods between mistic. detection and control in east Texas for 1974 and 1975 were 53 and 35 days, respectively. During this period, the Texas Forest Service was flying seven or more presuppression flights per year, which means that the average period of spot growth was between 66 and 84 days. If it is assumed that the average period a spot grows is 75 days, then the results in table 5 are obtained for each of the States.

On a statewide basis, the poorest predictions were for Arkansas and Tennessee, which are on the extreme

northern ranges of the SPB. Even including these States, the rank correlation between the observed and predicted volumes killed is 0.8 (Spearman's rank correlation, statistically significant; at the 99.5 percent level).

There are many potential sources of error in this comparison of predicted and observed volume killed by SPB. The data for observed volume killed are reported by each State. The degree of emphasis given to pest control activities, the level of the personnel involved, and the methods of obtaining reported volume killed vary greatly. The data are adequate for internal use by the States, but they may be less than satisfactory for model validation purposes. This situation is especially true for the volume killed but not Furthermore. the conversion sal vaged. factors used to obtain cubic-foot volume from cords and board-foot measure (fbm) can also be a source of bias.

There is also potential error associated with the method of determining

^aPredicted volume killed includes an average buffer strip volume of 30 percent for all salvaged spots.

^bObserved average annual volume killed, including buffer strip trees, for **1971** and **1980** (see footnote 4) is 12.788 x 10^6 ft³; cords and fhm were converted to cubic feet by using factors of 70 ft³ per cord and 210 ft³ per fbm.

^{&#}x27;Percent error = (predicted • observed)/predicted.

Texas Forest Service. Texas forest pest activity 1974-1975 and forest pest control section biennial report. TFS Circ. 226. College Station, TX; 1976.

the buffer strip volume from the simulation results. The State pest control workers reported that of the total volume salvaged, an average of 30 percent consisted of buffer strip trees. This value, expressed as a proportion, was multiplied by the reported average proportion of the total volume killed that was salvaged and by the total volume killed in each State to obtain the predicted volume of buffer strip trees. This volume was added to the predicted volume killed to obtain the combined volume lost due to SPB attack.

The FIA survey is also a source of potential error. The data were collected at a single point in time and were used to generate predicted losses, which were compared with average observed losses over a decade. Aggregate multi-year loss comparisons are necessary

since SPB populations are cyclic, whereas forest conditions are dynamically changing; thus, the overall susceptibility and vulnerability of the forest to SPB attack changes from year to year. Furthermore, some modification of the simulation program was necessary to accommodate FIA survey data. These modifications resulted in the use of some submodels with reduced predictive ability.

Lastly, the survey data obtained from the Southern Forest Experiment Station included age, expressed in 10-year increments, but did not include information on the number of trees per acre. Therefore, the number of growing-stock trees had to be generated from other survey plot variables, one of which was age. This procedure was less

Table 5.--Predicted and observed annual cubic-foot volume of timber killed by SPB if the average infestation grows for 75 days

State ^a	Predicted volume killed ^b	Observed volume killed ^c	Percent error ^d
	<u>ft³ x</u>	106	
AL	21. 250	34.374	-61.76
AR	8.982	1.560	82.44
GA	17.612	20.541	-16.63
LA	14. 215	4.434	68.81
MS	12.794	7.050	44.90
NC	26.930	21.272	21.01
SC	13.780	14.862	-7.85
TN	2.285	6.436	-181.66
TX	21. 011	14.137	32.72
VA	5.143	3.211	37.56

^{&#}x27;Oklahoma omitted because of negligible SPB activity.

^bPredicted volume killed includes an average buffer strip volume of 30 percent of salvaged spots.

^{&#}x27;Observed average annual volume killed, including buffer strip trees, for 1971 to 1980 (see footnote 4); cords and fbm were converted to cubic feet by using factors of $70 \, \text{ft}^3$ per cord and $210 \, \text{ft}^3$ per fbm.

dPercent error = (predicted • observed)/predicted.

than satisfactory, as is reflected in the simulation results shown in table 6.

These results are also reflected in the range of prediction errors for the States within each FIA survey region. For the Southern Station, the range was -181.66 to 82.44 percent, with five of the six States having errors greater than ±40 percent (table 5). For the Southeastern Station, the range was -16.63 to 37.56 percent, with three of four States having prediction errors less than ±21 percent (table 5). Furthermore, the relative rank of States in the Southeastern Station region is the same with regard to observed and predicted Based on these results, volumes killed. the projections for the States in the Southeastern Station survey region must be considered more reliable.

In addition to simulation of actual volume killed by SPB, estimates of growth loss due to premature harvest (salvaged) were also made. The first step in this process was the development of total cubic-foot volume equations for each State from FIA survey data. The form of equation was:

$$ln(V) = b_0 + b_1/A + b_2SC + b_3ln(B) + b_4ln(B)(A)$$
(13)

where:

v = total cubic-foot volume per acre

A = age in years

SC = site class

B = square feet of basal area per acre

To obtain the volume at the end of the projected rotation, harvest ages appropriate to the ownership and projected basal area at rotation were entered in the equation. The typical harvest or rotation ages provided by State forestry pest control officers for various ownership classes were 60 years for Federal lands, 45 years for State lands, 35 years for industry, and 45 years for NIPF lands. The difference between the volume at the time of attack by SPB and the projected volume at the end of the rotation was the estimated growth loss. No growth loss occurred if a stand was older than the appropriate rotation age for the ownership.

The process is dependent upon a method of projecting the basal area per acre at the rotation age. In this study, equations for predicting basal area were developed for different forest types from FIA survey data.

Table 6.--Comparison of predicted and observed volume of timber killed by SPB, based on an average period of spot growth of 75 days

Forest Experiment Station	Predicted volume killed	Observed volume killed	Percent error ^a
	• • • • <u>ft³ ></u>		
Southern ^b Southeastern ^c	$80.437 \\ 63.465$	67.991 59.886	$15.47 \\ 5.64$

^aPercent error = (predicted - observed)/predicted.

^bAlabama, Arkansas, Louisiana, Mississippi, Tennessee, Texas. (Oklahoma omitted because of negligible SPB activity.)

^{&#}x27; Georgi a, $\,\,$ North $\,$ Carol i na, $\,\,$ South $\,$ Carol i na, $\,\,$ Vi rgi ni a.

 $ln(B) = bo + b_1 SC + b_2/A$ (14)

where:

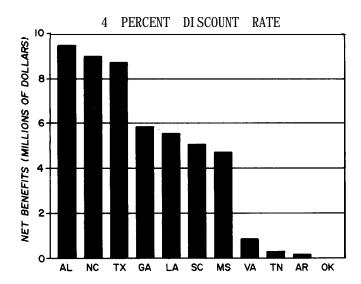
B = basal area per acre SC = site class A = age in years

This equation was used to calculate the difference (DBA) between the basal area per acre for the survey plot and the predicted basal area of the plot given the same site class and age. The equation was then used to predict the expected basal area at the end of the rotation given the same site class and This value was added to DBA to obtain the predicted basal area per acre at the end of the rotation. This approach seems to overpredict basal area at the end of the rotation if the initial basal area per acre is high. It also tends to underpredict for low ini-This method of protial basal areas. jection is less than satisfactory; however, due to lack of suitable basal area growth equations, it was the best of the many alternative prediction methods tested. Consequently, there is a source of potential error of unknown magnitude associated with the growth loss projections. Furthermore, the error associated with the growth loss estimated for States in the Southern Forest Experiment Station will be greater than for States from the Southeastern Station area due to the deficiencies in the survey mentioned previously.

Results

Figure 3 illustrates a ranking of the States by the optimal net benefits of SPB control for both the 4 and 10 percent discount rates. The States can be separated into three categories according to their level of net benefits for SPB control. Alabama, North Carolina, and Texas fall into the category of highest net benefits. Georgia, Louisiana, South Carolina, and Mississippi display a moderate level of net benefits. Virginia, Tennessee, Arkansas, and Oklahoma exhibit very low

levels of net benefits. Table 7 qives the benefit/cost ratios for the States. These ratios, at the 4 percent discount rate, range from a high of 9.35 for Alabama to a low of 1.12 for Oklahoma.



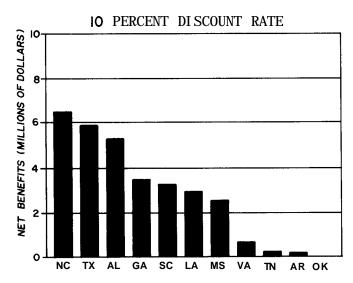


Figure 3.--Optimal net benefits of SPB control, at two discount rates, by State.

Table 7.--Summary of optimal total benefits and total costs for SPB control at two discount rates, assuming a moderate beetle population, in thousands of 1984 dollars, by State

State	Total benefits	Total costs	Net benefits	Benefit/ cost ratio
		4 PERCENT D	I SCOUNT RATE	
AL	10, 586	1,132	9,454	9.35
AR	240	107	133	2.24
LA	6,571	1,003	5,568	6.55
MS	5,882	1,169	4,713	5.03
NC	10,317	1,341	8,976	7.69
OK	0ª	0"	0ª	1.12
SC	6,024	950	5,074	6.34
TN	371	85	286	4.36
TX	10,468	1,764	8,704	5.94
VA	1,236	_ 381_	855_	3.26
Regi onal				
total	59,097	9,497	49,600	6.22
		10 PERCENT D	I SCOI JNT RATE	
AL	5, 912	622	5,290	9. 51
AR	197	88	109	2.25
GA	4,450	956	3,494	4.65
LA	3,519	587	2,932	5.99
MS	3,288	735	2,553	4.47
NC	7,472	969	6,503	7.71
0K	0ª	0 a	0ª	1.17
SC	3,917	644	3,273	6.08
TN	243	59	184	4.10
TX	7,242	1,333	5,909	5.43
VA	920	273	647	_3.39_
Regi onal				
total	37,160	6,266	30,894	5.93

[&]quot;Less than \$500.

Table 7 summarizes the optimal total costs (both direct and indirect) and benefits for SPB control at both the 4 and 10 percent real discount rates. These results represent the optimal solutions obtained for the individual FIA survey plots summed for each State. The results indicate that the calculations of benefits and costs were very sensitive to the different discount rates. At the 4 percent discount rate,

the total benefits were about \$59.1 million for the entire region, and the total costs were about \$9.5 million, yielding net benefits of \$49.6 million. The regional benefit/cost ratio was 6.22. At the 10 percent discount rate, the regional benefits were approximately \$37.2 million with total costs of \$6.3 million. Net benefits were \$30.9 million, and the benefit/cost ratio was 5.93.

Table 8.--Summary of optimal total benefits and direct costs for SPB control, assuming a moderate beetle population, in thousands of 1984 dollars, by State

State	Total benefits	Di rect costs	Benefits, net of direct costs	Benefit/direct cost ratio
		4 PERCENT	DI SCOUNT RATE	
AL	10, 586	970	9,616	10.91
AR	240	59	181	4.07
GA	7,402	1,121	6,281	6.60
LA	6,571	688	5,883	9.55
MS	5,882	861	5,021	6.83
NC	10,317	1,041	9,276	9.91
OK	0^a	Oa 	0a	1.96
SC	6,024	705	5,319	8.54
TX	371	73	298	5.08
TX	10,468	1,286	9,182	8.14
VA	1,236	<u>247</u>	989	<u>5.00</u>
Regi onal				
total	59, 097	7,051	52,046	8.38
		10 PERCENT D	DI SCOUNT RATE	
AL	5,912	599	5, 313	9. 86
AR	197	50	147	3.94
GA	4,450	813	3,637	5.47
LA	3,519	482	3,037	7.30
MS	3,288	615	2,673	5.34
NC	7,472	839	6,633	8.90
	0 ^a	O ^a	0 ^a	2.00
OK		558	3,359	7.02
SC	3,917		400	4.42
SC TN	243	5 5	188	
SC TN TX	243 7,242	1,041	6,201	6.96
SC TN	243			
SC TN TX	243 7,242	1,041	6,201	6.96

^aLess than \$500.

Table 8 contains study results similar to those in table 7 except that the direct costs of SPR control are given instead of the total control costs. These direct costs represent the actual cash outlays for presuppression flights, evaluation, and suppression, and exclude the opportunity costs involved in the harvesting of finan-

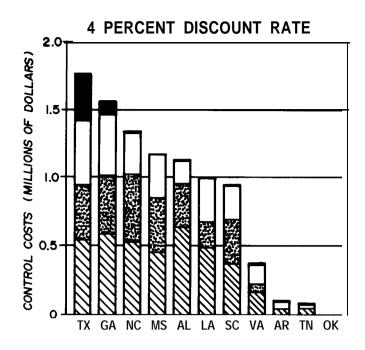
cially immature timber to control SPB. The regional benefits net of direct costs were \$52 million at the 4 percent discount rate, with a benefit/cost ratio of 8.38. At the 10 percent discount rate, the benefits net of direct costs were about \$32 million, yielding a benefit/cost ratio of 7.08.

Table 9.--Summary of optimal regional benefits and costs for SPB control at two discount rates, assuming a moderate beetle population, in thousands of 1984 dollars, by ownership class

Ownershi p cl ass	Total benefits	Total costs	Net benefits	Benefit/ cost ratio
		4 PERCENT	DI SCOUNT RATE	
Federal State Forest industry NIPF	6, 903 1, 371 12,498 38,325	908 173 2,208 6,208	5, 995 1,198 10,290 32,117	7.60 7.93 5.66 6.17
Regional total	59, 097	9, 497	49, 600	6.22
		10 PERCENT I	DI SCOUNT RATE	
Federal State Forest industry NIPF	2,942 997 10,204 23.017	488 124 1,804 3,850	2,454 873 8,400 19,167	6.03 8.07 5.66 5.98
Regi onal total	37,160	6,266	30,894	5. 93

Table 9 contains the regional benefits and costs by land ownership class. At the 4 percent discount rate, NIPF lands accounted for 64 percent of the total net benefits; forest industry lands, 20 percent; Federal lands, 12 percent; and State lands, 4 percent. NIPF lands represented 65 percent of the total costs; forest industry lands, 23

percent; Federal lands, 10 percent; and State lands, 2 percent. At the 10 percent discount rate, the general pattern of benefit and cost distribution remains the same, with NIPF lands accounting for the majority of benefits and costs. The benefit/cost ratios, at the 4 percent discount rate, range from 7.93 on State lands to 5.66 on forest industry lands.



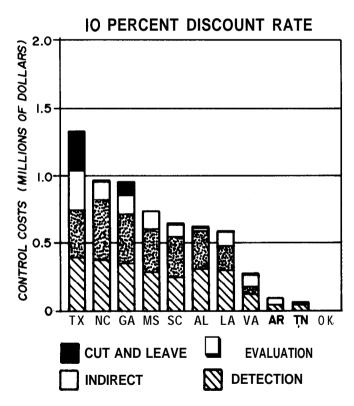


Figure 4.--Components of SPB control costs, at two discount rates, by State.

Figure 4 displays the breakdown of total control cost into the various direct and indirect cost components, by State. For most of the States, the cost of presuppression flights was the largest component of control cost,

averaging about 40 percent of total costs. The indirect cost of premature timber harvest was the next largest cost component, averaging about 28 percent of total costs. Evaluation costs averaged 27 percent of total costs, but the direct cost of cut-and-leave suppression constituted only 5 percent. The direct cut-and-leave cost is a larger share of total cost in Georgia and, particularly, Texas because the practice is more common there.

The complete, detailed study results are in the appendix. Table 10 contains the analysis results for the entire Southern region; tables 11-21 contain the results for the separate Each table contains the results States. for both the 4 and 10 percent discount Optimal total benefits, changes rates. in salvage value, direct and indirect costs, and benefit/cost ratios are given by land ownership class. Row and column totals may contain some slight rounding errors.

Conclusion and Discussion

The results of this study indicated that, in a year of typical SPB activity, substantial benefits could be realized from optimal economic control of SPB damage to commercial timber stands. At a 4 percent real rate to discount the value of timber losses, the optimal net benefits of control for the entire Southern region are estimated at about \$50 million, yielding a benefit/cost ratio of 6.22. Even at a 10 percent real discount rate, the regional net benefits are estimated to be more than \$30 million with a benefit/cost ratio of 5. 93.

States--Alabama. Seven Carol i na. Texas. Georgia, Loui si ana. South Carolina, and Mississippi-unquestionably warrant large SPB control Of those. Alabama. North efforts. Carol i na, and Texas are the three largest in terms of net benefits, averaging about \$9 million per State. The remaining four States could generate optimal net benefits of about \$5 million Vi rgi ni a, each. Tennessee, Arkansas,

and Oklahoma, under optimal SPB control conditions, would yield net benefits per State of less than \$1 million.

From the study results, the total regional optimal annual direct cost for SPB control is estimated to be about \$7 to \$5 million, depending upon the assumed discount rate of 4 or 10 percent. The majority of this respectively. control expenditure should be applied to presuppression flights and to the evaluation of SPB infestations. The direct cost associated with suppression, i.e., cut and leave and cut and salvage, is a minor component of control activities. The optimal direct control costs for Alabama, North Carolina, Texas, Georgia, Loui si ana, South Carol i na, and Mississippi range from about \$1.2 million to \$700,000 annually, per State, depending upon the assumed discount rate of 4 or 10 percent, respectively.

This study was an attempt to provide an economic basis for the planning of SPB control programs. As such, it represents a conceptually complex research activity. The simulation program seems to slightly overpredict volume killed by SPB on a regional Overprediction appears to be greater for the States in the FIA survey region of the Southern Forest Experiment Station. The predictions for States covered by the Southeastern Station survey (Georgia, North Carolina, South Carolina, Virginia) are very close to the observed volume killed when all the sources of potential error are con-The estimates of future growth si dered. loss due to premature death of the trees are subject to an unknown degree of error given the methods used to make the projections.

In spite of these caveats, the use of projected volume killed for the moderate population level weighted by the proportion of the region in an outbreak condition during an average year provides a realistic estimate of the direct mortality due to SPB attack. Because of these results, only the moderate SPB population projections were used in the economic analysis conducted with BEAM. Use of either the low or

high population values would result in extreme underestimates or overestimates of loss. Losses calculated from volume killed combined with growth loss due to premature death of trees caused by SPB attack provide the only estimates of the total regional impact of this pest available today. These should furnish suitable initial estimates for evaluating the economics of cooperative control programs.

Further investigations and refinement of the models and data are. warranted: however. perhaps. the authors express confidence in the results that have been generated. Also, sensitivity analyses were conducted to determine the effect of varying assumptions regarding salvage rates, timber prices, etc., on We determined that the study results. the results were not very sensitive to small changes in the data. changes in the discount rate had far greater impact on the study results than did changes in the other variables. Thus, data inaccuracies should not be a matter of great concern.

Acknowl edgment

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APPENDIX

Category	Federal	State	Forest industry	NI PF	Total		
Benefits Timber saved Change in salvage	\$7,142 -239		CENT DI SCO \$12,964 -466	UNT RATE \$39,523 -1,198	\$61,059 -1,962		
Total benefits	6,903	1,371	12,498	38,325	59,097		
Direct costs Presuppression flights Evaluation Cut and leave	352 237 56	73 45 _ 7	905 523 176	2,544 1,a42 292	3,875 2,645 531		
Total direct costs	644	125	1,604	4,677	7,051		
Indirect costs (buffer timber)	264	48	_ 604_	1,530	2,446		
Total costs	908	173	2,208	6,208	9,497		
Net benefits	\$5,995	\$1,198	\$10,290	\$32,117	\$49,600		
Benefit/cost ratio	7.60	7.93	5.66	6.17	6.22		
	10 PERCENT DI SCOUNT RATE						
Benefits Timber saved Change in salvage	\$2,935	\$1,041 -43	\$10,560	\$23,030 -13	\$37,567 -406		
Total benefits	2,942	997	10,204	23,017	\$7,161		
Direct costs Presuppression flights Evaluation Cut and leave	175 200 51	54 40 6	732 490 165	1,512 1,576 242	2,474 2,305 464		
Total direct costs	427	100	1,386	3,330	5,243		
Indirect costs (buffer timber)	61_	23	418	520	1.022		
Total costs	488	124	1,804	3,850	6,266		
Net benefits	\$2,455	\$874	\$8,400	\$19,167	\$30,895		
Benefit/cost ratio	6.03	a.07	5.66	5.98	5.93		

Table $11.\mbox{--Optimal}$ level for SPB control, in thousands of dollars, by ownership class, for Alabama

Cagetory	Federal	State	Forest industry	NI PF	Total
Benefits		4 PERC	ENT DI SCOU	NT RATE	
Timber saved Change in salvage	\$645 -66	\$232 <u>-26</u>	\$2,804 -217	\$7,954 -740	\$11,636 -1,050
Total benefits	579	206	2,587	7,214	10,586
Direct costs Presuppression flights Evaluation Cut and leave	33 15 1	9 5 0	174 82 3	426 214 9	642 316 13
Total direct costs	48	14	260	649	970
Indirect costs (buffer timber)	12	1	50	98	162
Total costs	61	14	310	747	1,132
Net benefits	\$519	\$192	\$2,277	\$6,467	\$9,454
Benefit/cost ratio	9.54	14.44	8.35	9.66	9.35
		10 PERC	ENT DI SCOU	NT RATE	
Benefits Timber saved Change in salvage	\$110 49	\$171 <u>-18</u>	\$2,040 -139	\$3,726 -27	\$6,047 -136
Total benefits	159	153	1,901	3, 699	5, 912
Direct costs Presuppression flights Evaluation Cut and leave	9 11 1	6 4 0	119 75 3	183 180 8	316 270 12
Total direct costs	20	10	198	371	599
Indirect costs (buffer timber)	1	0	17	5	23
Total costs	21	10	214	376	622
Net benefits	\$138	\$143	\$1, 687	\$3,323	\$5, 290
Benefit/cost ratio	7.51	15. 26	8.87	9. 84	9.51

Table 12.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Arkansas

Catetory	Federal	State	Forest industry	NI PF	Total
		4 PERCE	NT DI SCOUNT	RATE	
Benefits Timber saved Change in salvage	\$0 0	\$7 0	\$115 -3	\$124 <u>-3</u>	\$246 - 7
Total benefits	0	7	112	121	240
Direct costs Presuppression flights Evaluation Cut and leave	0 0 0	1 0 0	22 2 5	22 2 5	45 4 10
Total direct costs	0	2	29	29	59
Indirect costs (buffer timber)	0	1	24	23	48
Total costs	0	3	52	51	107
Net benefits	\$0	\$4	\$60	\$69	\$133
Benefit/cost ratio	** **	2.24	2. 14	2.34	2.24
Benefits Timber saved Change in salvage	\$0 0	10 PERCEN \$7 0	NT DI SCOUNT \$108 -3	RATE \$87 -2	\$203 -5
Total benefits	0	7	105	85	197
Direct costs Presuppression flights Evaluation Cut and leave	0 0 0	1 0 0	2 0 2 5	16 2 5	37 4 9
Total direct costs	0	2	26	23	50
Indirect costs (buffer timber)	0	1	22	15	38
Total costs	0	3	48	37	88
Net benefits	\$0	\$4	\$58	\$48	\$109
Benefit/cost ratio		2.36	2.21	2.28	2.25

Table 13.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Georgia

Category	Federal	State	Forest industry	NI PF	Total
Paradit a		4 PERO	CENT DI SCOUN	VT RATE	
Benefits Timber saved Change in salvage	\$681	\$50 0	\$1,079 8	\$5,628 -30	\$7,438 -37
Total benefits	682	50	1,071	5,599	7,402
Direct costs Presuppression flights Evaluation Cut and leave	43 31 <u>7</u>	5 3 1	97 53 <u>17</u>	440 345 78	586 432 103
Total direct costs	81	9	168	863	1, 121
Indirect costs (buffer timber)	41	4	76	324	444
Total costs	121	13	244	1,187	1,565
Net benefits	\$561	\$37	\$828	\$4,412	\$5,837
Benefit/cost ratio	5.62	3.77	4.40	4.72	4.73
		10 PERO	CENT DI SCOUN	IT RATE	
Benefits Timber saved Change in salvage	\$3 82 2 2	\$25 2	\$840	\$3,030 _ 143_	\$ 4,276 173
Total benefits	403	27	847	3,172	4,450
Direct costs Presuppression flights Evaluation Cut and leave	25 26 6	3 2 1	72 50 17	251 2 89 71	351 367 95
Total direct costs	5 7	6	139	611	813
Indirect costs (buffer timber)	<u>15</u>	1	37	_ 90_	143
Total costs	72	7	176	701	956
Net benefits	\$332	\$20	\$671	\$2,472	\$3,493
Benefit/cost ratio	5.62	3.65	4.81	4.53	4.65

Category	Federal	State	Forest industry	NI PF	Total
P. Chr.		4 PERO	CENT DI SCOUN	NT RATE	
Benefits Timber saved Change in salvage	\$1, 038 - 41	\$322 -13	\$2,175 -66	\$3,254 -97	\$6, 789 -218
Total benefits	997	308	2,109	3,157	6,571
Direct costs Presuppression flights Evaluation Cut and leave	5 2 2 1 1	14 6 0	163 64 3	258 102 4	487 194 8
Total direct costs	74	20	230	364	688
Indirect costs (buffer timber)	34	10	106	164	315
Total costs	108	30	336	528	1,003
Net benefits	\$889	\$278	\$1,772	\$2,629	\$5,568
Benefit/cost ratio	9.25	10.20	6.27	5.98	6.55
		10 PERC	CENT DI SCOUM	VT RATE	
Benefits Timber saved Change in salvage	\$230 -13	\$161 -12	\$1,737 -61	\$1,544 <u>-67</u>	\$3,672 -153
Total benefits	218	149	1,676	1,477	3,519
Direct costs Presuppression flights Evaluation Cut and leave	17 17 <u>1</u>	9 6 0	137 61 3	139 88 4	302 172 _ 7_
Total direct costs	3 5	15	201	231	482
Indirect costs (buffer timber)	2	1	73	30	106
Total costs	37	16	273	261	587
Net benefits	\$180	\$133	\$1,402	\$1,217	\$2,932
Benefit/cost ratio	5.82	9.46	6.13	5.67	5.99

Table 15.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Mississippi

Category	Federal	State	Forest industry	NI PF	Total		
Benefits		4 PERC	CENT DI SCOUN	NT RATE			
Timber saved Change in salvage	\$1,040 -32	\$115 -3	\$1,468 -39	\$3,428 -95	\$6,051 -169		
Total benefits	1,008	112	1,429	3,333	5,882		
Direct costs Presuppression flights Evaluation Cut and leave	72 50 1	12 8 0	101 98 2	276 237 5	460 392 B		
Total direct costs	123	20	201	517	861		
Indirect costs (buffer timber)	51	8	66	184	309		
Total costs	174	28	267	701	1,169		
Net benefits	\$834	\$85	\$1,162	\$2,632	\$4,712		
Benefit/cost ratio	5.80	4.07	5.35	4.75	5.03		
	10 PERCENT DI SCOUNT RATE						
Benefits Timber saved Change in salvage	\$401 -15	\$88 -3	\$1,082 -36	\$1,844 -72	\$3,414 -126		
Total benefits	386	85	1,046	1,772	3,288		
Direct costs Presuppression flights Evaluation	35 38	8 6	79	164	$\begin{array}{c} 286 \\ 323 \end{array}$		
Cut and leave	1 74	<u>0</u> 14	$\frac{902}{172}$	188 4 356	615		
Total direct costs Indirect costs (buffer timber)		5	43	64	120		
Total costs	<u>8</u> 82	19	214	420	735		
20002			= =				
Net benefits	\$304	\$66	\$832	\$1,352	\$2,553		
Benefit/cost ratio	4.69	4.42	4.89	4.22	4.47		

 $Table\ 16.\hbox{--Optimal}\ level\ for\ SPB\ control,\ in\ thousands\ of\ dollars,\ by\ ownership\ class,\ for\ North\ Carolina$

Category	Federal	State	Forest industry	NI PF	Total
		4 PERC	CENT DISCOU	NT RATE	
Benefits Timber saved Change in salvage	\$332 <u>-1</u>	\$292 8_	\$509 <u>-3</u>	\$9,284 89_	\$10,417 -100
Total benefits	332	284	506	9,195	10,317
Direct costs Presuppression flights Evaluation Cut and leave	24 16 1	12 9 0	43 21 1	449 454 11	528 500 13
Total direct costs	41	21	65	914	1,041
Indirect costs (buffer timber)	11	7	25	257_	300
Total costs	52	28	90	1,171	1,341
Net benefits	\$280	\$256	\$416	\$8,024	\$8,975
Benefit/cost ratio	6.36	10.31	5.60	7.85	7.69
		10 PERC	CENT DISCOU	INT RATE	
Benefits Timber saved Change in salvage	\$194 12	\$736 -6	\$451	\$6,548 <u>38</u>	\$7,439 43
Total benefits	205	230	450	6,586	7,472
Direct costs Presuppression flights Evaluation Cut and leave	14 15 _ 1_	9 9 0	36 20 1	317 404 10	378 449 12
Total direct costs	30	19	58	732	839
Indirect costs (buffer timber)	3	_ 3	17	107	131
Total costs	33	22	75	839	969
Net benefits	\$173	\$208	\$375	\$5,747	\$6,503
Benefit/cost ratio	6.30	10.36	6.01	7.85	7.71

Category	Federal	State i	Forest ndustry	NI PF	Total
Benefits Timber saved Change in salvage	\$0.52 02	4 PERCEN	\$ 0	RATE \$0	\$0.52
Total benefits	•51	0	0	0	<u>02</u> .51
Direct costs Presuppression flights Evaluation Cut and leave	.22 .01 .03	0 0	0 0 0	0 0 0	.22 .01 .03
Total direct costs	.26	0	0	0	.26
Indirect costs (buffer timber)	<u>.19</u>	0	0	0	<u>.19</u>
Total costs	•45	0	0	0	.45
Net benefits	\$.05	\$0	\$ 0	\$0	\$.05
Benefit/cost ratio	1.12				1.12
Benefits Timber saved Change in salvage	\$0.31	10 PERCEN	T DI SCOUNT \$ 0	RATE \$ 0	\$0.31 •01
Total benefits	.32	0	0	0	.32
Direct costs Presuppression flights Evaluation Cut and leave	.11 .01 .04	0 0 0	0 0	0 0	.11 .01 .04
Total direct costs	.16	0	0	0	.16
Indirect costs (buffer timber)	<u>.12</u>	0	0	0	.12
Total costs	.27	0	0	0	.27
Net benefits	\$. 05	\$0	\$0	\$ 0	\$.05
Benefit/cost ratio	1.17				1.17

Table 18.--Optimal level for SPB control, in thousands of dollars, by ownership class, for South Carolina

Category	Federal	State	Forest industry	NI PF	Total
Benefits		4 PERO	CENT DI SCOU	NT RATE	
Timber saved Change in salvage	\$577 9	\$159 -2	\$566 -3	\$4,724 6_	\$6,025 -1
Total benefits	586	156	563	4,718	6,024
Direct costs Presuppression flights Evaluation Cut and leave	38 26 1	7 6 0	48 26	279 267	371 324 9
Total direct costs	64	13	75	552	705
Indirect costs (buffer timber)	25	5	36	179	245
Total costs	90	18	110	732	950
Net benefits	\$497	\$138	\$453	\$3,986	\$5,074
Benefit/cost ratio	6.54	8.58	5.10	6.45	6.34
		10 PERC	ENT DI SCOU	NT RATE	
Benefits Timber saved Change in salvage	\$350 33	\$139 <u>-1</u>	\$442	\$2,870	\$3,801 117
Total benefits	383	138	444	2,953	3,917
Direct costs Presuppression flights Evaluation Cut and leave	21 23 1	6 5 0	39 24 1	185 246 7	251 298 9
Total direct costs	45	12	64	437	558
Indirect costs (buffer timber)	8	3	19	56	86
Total costs	53	15	83	493	644
Net benefits	\$330	\$123	\$360	\$2,460	\$3,273
Benefit/cost ratio	7.23	9.47	5.33	5.99	6.08

Category	Federal	State	Forest industry	NI PF	Total	
Benefits		T RATE				
Timber saved Change in salvage	\$104 0	\$14 1	\$26	\$223 <u>3</u>	\$367 <u>4</u>	
Total benefits	104	15	26	225	371	
Direct costs Presuppression flights Evaluation Cut and leave	8 4 0	3 1 0	4 2 0	35 14 1	51 21 1	
Total direct costs	12	4	6	50	73	
Indirect costs (buffer timber)	2	1	_1	8	12	
Total costs	15	5	7	58	85	
Net benefits	\$90	\$10	\$19	\$167	\$286	
Benefit/cost ratio	7.19	2.83	3.73	3.86	4.36	
	10 PERCENT DI SCOUNT RATE					
Benefits Timber saved Change in salvage	\$53 4	\$11	\$23 _	\$141 	\$228 16	
Total benefits	56	12	24	151	243	
Direct costs Presuppression flights Evaluation Cut and leave	5 3 0	3 1 0	4 1 _ 0_	23 12 1	35 18 1	
Total direct costs	9	4	5	37	55	
Indirect costs (buffer timber)	0	0	1	3	_5	
Total costs	9	4	6	40	59	
Net benefits	\$47	\$8	\$18	\$111	\$184	
Benefit/cost ratio	6.15	2.82	3.92	3.79	4.10	

Table 20.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Texas

Category	Federal	State	Forest industry	NI PF	Total		
	4 PERCENT DI SCOUNT RATE						
Benefits Timber saved Change in salvage	\$2, 671 -110	\$190 -6	\$4,020 -126	\$3, 964 - 135	\$10,845 -377		
Total benefits	2,561	183	3,894	3, 829	10,468		
Direct costs Presuppression flights Evaluation Cut and leave	71 70 43	6 6 4	228 164 140	238 159 157	543 399 344		
Total direct costs	185	16	532	553	1,286		
Indirect costs (buffer timber)	80	8	197	193	_ 478_		
Total costs	265	24	729	746	1,764		
Net benefits	\$2,297	\$160	\$3,165	\$3,083	\$8,704		
Benefit/cost ratio	9.68	7.76	5.34	5.13	5.94		
	10 PERCENT DI SCOUNT RATE						
Benefits Timber saved Change in Salvage	\$1,184 -85	\$159 -6	\$3,665 -123	\$2,568 -119	\$7,575 -333		
Total benefits	1,099	153	3,541	2,448	7,242		
Direct costs Presuppression flights Evaluation Cut and leave	42 63 40	5 5 _4	204 156 131	147 126 119	398 350 293		
Total direct costs	145	13	491	391	1,041		
Indirect costs (buffer timber)	21	6	172	93	292		
Total costs	166	19	663	485	1,333		
Net benefits	\$933	\$134	\$2, 878	\$1,964	\$5,909		
Benefit/cost ratio	6.61	8. 10	5.34	5.05	5.43		

Table 21.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Virginia

Category	Federal	State	Forest industry	NI PF	Total
Dana C: ta	- maper s	4 PERC	CENT DI SCOUNT	RATE	
Benefits Timber saved Change in salvage	\$53 0	\$50 -1	\$202 2_	\$941 6_	\$1,245 <u>-8</u>
Total benefits	53	49	200	935	1,237
Direct costs Presuppression flights Evaluation Cut and leave	11 4 1	4 2 1	26 10 <u>3</u>	123 48 _ 16_	163 63 21
Total direct costs	16	6	39	186	247
Indirect costs (buffer timber)	7	3	22	99	132
Total costs	23	10	61	285	380
Net benefits	\$30	\$39	\$139	\$650	\$858
Benefit/cost ratio	2.31	4.93	3.27	3.28	3.26
	10 PERCENT DI SCOUNT RATE				
Benefits Timber saved Change in salvage	\$31 1	\$45 -1	\$172 -1	\$673 0	\$921 -1
Total benefits	32	45	171	673	920
Direct costs Presuppression flights Evaluation Cut and leave	7 3 1	42 O	22.9 3	8741 14	119 55 _ 19_
Total direct costs	11	6	34	142	192
Indirect costs (buffer timber)	_3	_ 3_	<u>17</u>	57	80
Total costs	14	9	51	198	272
Net benefits	\$19	\$36	\$120	\$474	\$649
Benefit/cost ratio	2.34	5.22	3.34	3.39	3.39

de Steigwer, J.E.; Hedden, Roy L.; Pye, John M.

Optimal level of expenditure to control the southern pine beetle. Res. Pap. SE-263. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1987. 30 pp.

Optimal level of expenditure to control damage to **Commercial** timber stands by the southern pine beetle was determined by models that simulated and analyzed beetle attacks during **a** typical season for 11 Southern States. At a real discount rate of 4 percent, maximized net benefits for the Southern region are estimated at about \$50 million; at 10 percent, more than \$30 million. Methods and costs for detection, evaluation, and suppression of beetle infestation are discussed. Tables of optimal level for the 11 States are included.

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KEYWORDS: Dendroctonus frontalis, CLEMBEETLE, OVERFLIGHT, BEAM, cut and leave, cut and salvage, presuppression flights.



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